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FOUNDATION CONDITIONS IN CHARLESTON, S. C.

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FOUNDATION CONDITIONS IN CHARLESTON, S. C.

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INTRODUCTION

It requires only a brief time for an engineer who comes to Charleston to realize that he has reached an area with extremely interesting foundation conditions. Engineers from "upstate" South Carolina have been known to say that Charleston is resting on rotten soil which they discarded as being worthless and washed down to the "low-country" with the river water. One who knows the great assortment of soils which can be encountered in a small area believes there is more truth than fiction here.

In this paper some of these soil conditions and foundation problems will be discussed. To do this it will be necessary to first study the general geology of the area in order to understand the formation of the soil strata. Then there will be presented some of the various soil profiles encountered, with identification and descriptions of some of the most interesting soils. It is believed that the foundation problems caused by these conditions and the solutions to these problems will be of interest to other engineers in similar areas.

Geology of the Area

The Charleston area is located in the terraced section of the South Carolina coastal plain. It lies between the Ashley and Cooper Rivers which are tidal streams with mud flats and bays at their mouths. The terraced section was subject to many emergences and submergences during its geological history which caused the shore line to change many times. When the underlying rock stratum was at the surface, streams etched their topography, and then, upon being submerged again below the sea, the valleys formed by the streams were filled with sand, clay, and silt, forming a new rock stratum. In this manner approximately five different rock or soil formations of sedimentary origin were made.

Deepest of these layers is the Black Mingo formation, a mixture of well consolidated sand, clay and shales. This rock is nearly black in color and quite permeable, due to the high sand content. Overlying this stratum is the Santee limestone formation which is nearly pure calcium carbonate. It is often granular and rather poorly cemented, with deposits of chert and flint sometimes present due to leaching of shell material. The color varies from a greenish gray to a light gray and the stone is usually quite hard.

The next three layers are those which are of greatest importance for foundation study. These are the Cooper Marl, Hawthorn, and Pleistocene layers. The latter two layers represent the assorted mixture of sands, clays, shells, and organic matter which lie between the marl and the ground surface. The

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marl stratum gives a base for deep foundations, and the soil overlying the marl supports most of the light structures in the area. In the next section of this paper, these soils will be discussed in greater detail.

Soil Profiles and Description of Soil

Most of the soil exploration for structures in this area is carried into the marl stratum. This stratum might be encountered anywhere from 30' to 100' below ground. The soil profile down to this marl is very non-homogeneous due to its sedimentary origin and deserves comment. The following is a representative soil profile as often found in borings, with the admission being readily made that variations are abundant. Each area must be investigated to determine its particular soil profile.

Usually there is a sand surface layer ranging from a few feet to 15' or 20' thick. This mat may have been a deposit placed by nature or may be an uncompacted man-made fill of variable age. It is usually loose or very loose, ranging between four and ten blows per foot in the standard penetration test, and is from fine to medium in size. The dry density is approximately 100# cu. ft. with a void ratio around .60 to .70. This first mat also might be a general mixture of bricks, bottles, tin cans, and other debris. Now underlying this is usually a layer of very soft to medium organic silt or clay ranging in thickness from 5' or 10' to as much as 40' or 50'. This material is locally called "pluff mud" and may be seen in the marshes surrounding Charleston. It is an interesting soil, being a mixture of silt, clay, and decomposed organic matter carried there and deposited by the rivers and tidal water. It is often so soft that it is possible for two men to push a 2-1/2" steel casing 35' into it without any driving. There have been cases where one blow of the 140# hammer dropping 30" drove the spoon 4' into the clay. It should be recalled that very soft clay is classified as that requiring less than 2 blows to drive the spoon one foot. Observers have reported piles being driven in this soil in which the dead weight of the hammer drove the pile 40' or 50' without a blow being struck.

As may be assumed this organic clay is extremely compressible, consolidating many inches under a small load. Even a shallow fill placed on it will often cause great settlement. The soil ranges from dark gray or blue to almost black in color, drying out to a light gray. It is quite odorous when first excavated due to the products of organic decomposition. Natural moisture content varies from 50% to 200%. Atterberg Limit Tests run on the clay without previous drying show a range of Liquid Limit from 70 to 150 and a range of Plastic Limit from 30 to 50. Oven drying of the soil before testing produced a drop in the Liquid Limit of approximately 40% and a lesser drop in the Plastic Limit. Unconfined Compression tests show a strength from practically zero to .5 T/sq.ft. where the soil has been consolidated to some extent by overburden.

To make this soil more complex, there are found in many places thin layers of peat in the organic clay. This peat is brown to black in color and has definite vegetable fibers still visible, since they are only partially decomposed. Often the spoon will penetrate an old tree stump 40' or 50' in the ground, which at one time in history was at the ground surface. Most of the time there are calcareous shells in the clay, either microscopic or visible to the eye.

Then there are found various layers of shells, organic clay, and sand floating somewhere in this deep layer of organic matter. Now one of these shell

layers gives good resistance to a pile being driven and thus gives a sense of false security to one who does not know that this layer is probably underlain by more soft material. For example, in driving piles for the recent construction of an oil tank, the piles were driven through the marsh to good resistance according to a pile driving formula. Within six months the tank had a differential settlement of one foot; total settlement is unknown. Borings taken later in the vicinity reveal that this tank is probably resting on a shell mat with soft clay below.

Under this organic clay there usually exists a layer of gray or brown sand of loose to medium density varying from a few feet in thickness to as much as 20'. This will gain more clay content as depth progresses until we reach the stratum of stiff to very stiff brownish green calcareous clay which is called Cooper Marl. As has been stated, the depth to this layer will vary considerably, but will average around 50' to 60' over the Charleston area. As an example of this variation in depth, on a recent soil investigation there was almost a 30' differential within one city block. Even under individual buildings the depth may vary by 10' or more due to the original stream beds etched in the marl long ago. On the other hand one investigation covering two city blocks showed only a 5' differential in the depth to marl.

This marl is an unusual soil; there are many differences of opinion as to just what is marl. Around Charleston the author has been shown everything from pluff mud to cemented sand and has been assured it was marl. The material which will be described here conforms to the definitions of marl as found in most publications on soil mechanics. It is a clay, having a Liquid Limit in the range of 45 to 70, and a Plastic Limit of 25 to 40. The natural moisture content is approximately 40% to 50%. It is definitely plastic and has high dry strength, due partially to its clay content and partially to the cementing action of the microscopic shells found in it. A hydrochloric acid test proves readily that there is a high content of calcareous matter, some authorities claiming almost 75% content by volume. There is also a variable amount of fine sand and silt usually present in this clay. If it dries out below the shrinkage limit, it is subject to severe slaking if saturated once again. Unconfined compression tests run on various samples show a strength varying from 1 T/sq. ft., to slightly over 3 T/sq. ft.

This stratum varies in thickness, but it is claimed by geologists that it is approximately 200' thick in Charleston itself. The two deepest borings known to the author penetrated the marl approximately 70' in one case and 135' in the other. It is interesting to note that the stiffness of the marl does not show material increase as the depth grows greater. Within one drill hole the results of the standard penetration test may vary from 8 to 20 blows per foot, with both softer and harder layers being encountered at various depths. Piles driven into this soil will reach high resistance with wooden piles often reaching refusal after 5' to 10' penetration; other piles can be driven deeper.

Undoubtedly this marl stratum is of great importance to the foundation engineer since practically all major structures are built on piles driven into this material or the sand immediately over it. So far as can be determined no building founded on it has had any settlement of consequence.

Foundation Problems and Procedures

Now after giving a brief description of the types of soil encountered beneath Charleston, perhaps it can be seen that often there are interesting foundation problems. Most of the small and inexpensive structures are supported on footings resting on the sand mat. If the mat is thick enough and has

stability itself no great settlement results. The stress caused by the building simply is of little consequence when it reaches the soft layer beneath. Other people are fortunate enough to have an area with mostly inorganic soil down to the marl. In this case the sand is usually loose and often it is necessary to reduce the unit load to 1500 to 2000 # sq. ft. Even with this small load differential settlement often occurs, causing cracking.

Unfortunately this situation of a deep sand layer is sometimes claimed in a rather loose manner by the real-estate man who states it is "virgin" land. Beware of this claim; neighbors in the area generally can tell of the "virgin" land being hauled in by truck a few years ago to cover a marsh area. In several cases investigated recently, the "virgin" land has required piles over 50' long to reach solid bearing.

Another situation gives great concern. Years ago a large area of Charleston was cut through in places by streams or creeks with organic silt and clay bottoms. In the period elapsing these beds were filled in and their presence forgotten. From the surface the soil is quite acceptable; a nearby building on footings may show no cracks or evidence of excessive settlement. Yet borings will show as much as 40' of organic matter underlying the fill. Now this situation can exist right in the middle of the city; it is not limited to the area near the marshes. In a recent addition to a church it was found that the original building rested on footings on the bank of an old creek. A new extension to the same building rested square in the creek and had to be placed on 45' to 55' piles. Even The Citadel has its old creek bed; one new building is in this area and is supported by 55' piles, although all other buildings rest on footings.

Incidentally there is sufficient reason not to trust too much the "old saying" that if good sized trees are present it is "virgin" land. In one oil tank layout near the Cooper River it was necessary to clear the area of nearly a forest before construction could start. Yet there was found only a 4' or 5' sand mat overlying 6' to 10' of very soft organic clay and peat; this soil had to be excavated and backfilled with compacted sand before placing the tanks. Later it was discovered that some old residents of the area recalled the filling of the marsh thirty years before.

The use of pile foundations has been spoken of before in this article. Most of the larger structures and even many minor ones must rest on piles driven into the marl or the sand overlying it. As previously stated, the organic soil is simply too compressible to bear heavy loads. Various types of piles are used including wooden, steel, and concrete piles. The wooden piles are usually untreated and are of the composite type, with cut off being below Ground Water Table and concrete being used to bring the pile to the surface. Pressure treated creosoted piles are used where the builder wishes to bring the wooden pile above Ground Water Table and, of course, in water front work. Wooden piles up to 75' to 85' long are still obtainable if searched for long enough. These piles are usually loaded to 15 to 20 Tons. Concrete piles are of both the precast and cast-in-place types, with the latter predominating for buildings. Some of these have been over 90' long. For example, the new Teaching Hospital of The Medical College rests on approximately 2200 cast-in-place concrete piles ranging from 76' to 92' long. These piles, driven into the marl, were loaded to 30 Tons. Individual load tests were run on 3 of these piles, with a total load on each of 130 Tons. In no case did the net settlement exceed 1/4''. The bearing as checked by the Engineering News Formula varied from 19 to 34 Tons.

Steel H piles have been used for water front work but, to this author's knowledge, none has been used for buildings. In one particular case this

relatively non-displacement pile would have been quite valuable. A building was resting on 40' piles driven into a sand and shell mat overlying organic clay. A new extension of greater height was to be built adjoining this building and 70' wooden piles were to be driven into the marl. As driving proceeded the piles had to displace the clay underlying the sand and shell mat, and the mat came up raising the center of the building about 6'' and cracking it down the middle. The damage was so severe that a tarpaulin had to be kept over the crack to keep the rain from going in. The use of H piles would have given less displacement of the clay.

Even minor buildings must often be placed on piles unless great settlement is to be expected. Soil investigation made recently for two service stations showed that each required 40' to 45' piles for stability. In one case a man failed to pile a concrete floor in a building resting on piles. Before he was even finished he had nearly a foot of settlement of the floor. Houses along the famous Battery require piles from 40' to 60' long; often the cost of the foundation is much out of proportion to the cost of the building. Sometimes sidewalks and steps around a building on piles will settle and cause much inconvenience. A fourteen-story apartment house recently completed along the Ashley River is built in a filled marsh area and rests on piles. The fill itself has settled almost a foot and sidewalks, roads, and service lines have followed it down. Not only has this settlement caused inconvenience, but it has been quite difficult to maintain service lines to the building.

The principle of flotation of buildings has not been used to much extent in this area. One three-story building now being erected is using this principle, having sufficient excavation and water buoyancy to counteract at least partially the weight of the building. Much difficulty has been encountered with the ground water, and most engineers and contractors do not desire to do much excavation. The Ground Water Table varies from a depth of 2' to 10' around the area, usually being within 5' of the surface. This fact, accompanied with the presence of the previous sand mat, makes excavation very expensive. Since the marl stratum can be reached with piles of reasonable length, it is not believed that the Floating Foundation principle will receive wide usage here in the near future.

Foundation Investigation

Now what foundation investigation is usually made in this area with these subsurface conditions? Great changes in the attitude of architects and engineers have taken place in the past decade. Previous to around 1940, very little soil investigation was made in this area. Buildings were erected on foundations designed primarily from experience or judgment. Many designs were satisfactory; others were not. Soil borings were rarely taken. If piles were to be driven, their required length was determined from a "test pile" which was driven until the formula said to stop. The prevailing idea was that if piles were driven all was well. The author recalls only too vividly his thoughts when an architect on one of his early consulting jobs told the owner that nothing could happen since piles were being driven. No borings had been taken on this job and the type of soil beneath the piles was unknown.

Gradually a change began to appear. Architects, engineers, and contractors began to wonder what soil was actually supporting their footings or piles and what lay below. Many unpleasant consequences of lack of foundation exploration became known to them. It simply became good business to give more attention to the foundations. Contractors who for years had just gone

ahead on a "prayer and a guess" are now requesting soil exploration. There are, of course, still some who claim it is a waste of money. It is believed their ranks will grow smaller as each encounters some job which ends with unpleasant results.

Foundation investigation usually consists of soil borings into the marl and possible plate load tests where footings are being contemplated or pile load tests for deep foundations. Most borings are of the "dry-sample" or spoon type with the standard penetration test being used to estimate comparative density or consistency. There have been some borings taken with rotary equipment or with other types of samplers. In various cases relatively undisturbed samples such as the Shelby Tube type have been taken, principally in the marl.

There is not a great deal of laboratory testing of samples; clients still are reluctant to pay for this service. Practically all such laboratory testing has been done for various governmental agencies in the vicinity, rarely for private industry. It is simply a matter of not being able to change the established customs of decades in a matter of a few years. Also it must be remembered that in an area with such varied deposits of sedimentary soil, results of tests would have to be interpreted with great care. Otherwise there is the danger of obtaining only the characteristics of a small sample of soil and not those of the entire stratum. Moreover when organic soil is encountered which is so soft that one man can obtain the sample merely by pressing hard on the spoon, no tests are needed to convince a person that this is not desirable bearing material. It is hoped that a more extensive testing program of the marl can be developed whereby consolidation and various strength tests can be run on Shelby Tube samples.

CONCLUSION

The field of scientific Foundation Engineering is still in its infancy in this vicinity. The Subsurface conditions placed there by nature have made the area a fertile field for a Foundation Engineer. It has often been necessary to place buildings on foundations which would not satisfy the most critical engineer; existing conditions must be accepted and a solution to the problem must be found. Although much advancement has been made in the outlook of owners and builders, much remains to be done. It is believed sincerely that in the years to come there will be greater understanding of the fact that the proper use of Soil Mechanics in Foundation Engineering is not a luxury or "fad"; it is a necessity for economical and proper foundation design.